1. INTRODUCTION

1.1. PURPOSE

Ege-SAT ………

(Payload: The aim is to efficiently detect forest areas near the Aegean Region of Turkey for 6 years. For this purpose we utilize a camera as a payload and take pictures of the region. Pictures are then supplied to the necessary application. As a result we will be able to gather the forest area measurements of the region over six years.)

2. EGE-SAT OVERVIEW

2.1. MISSION OBJECTIVES

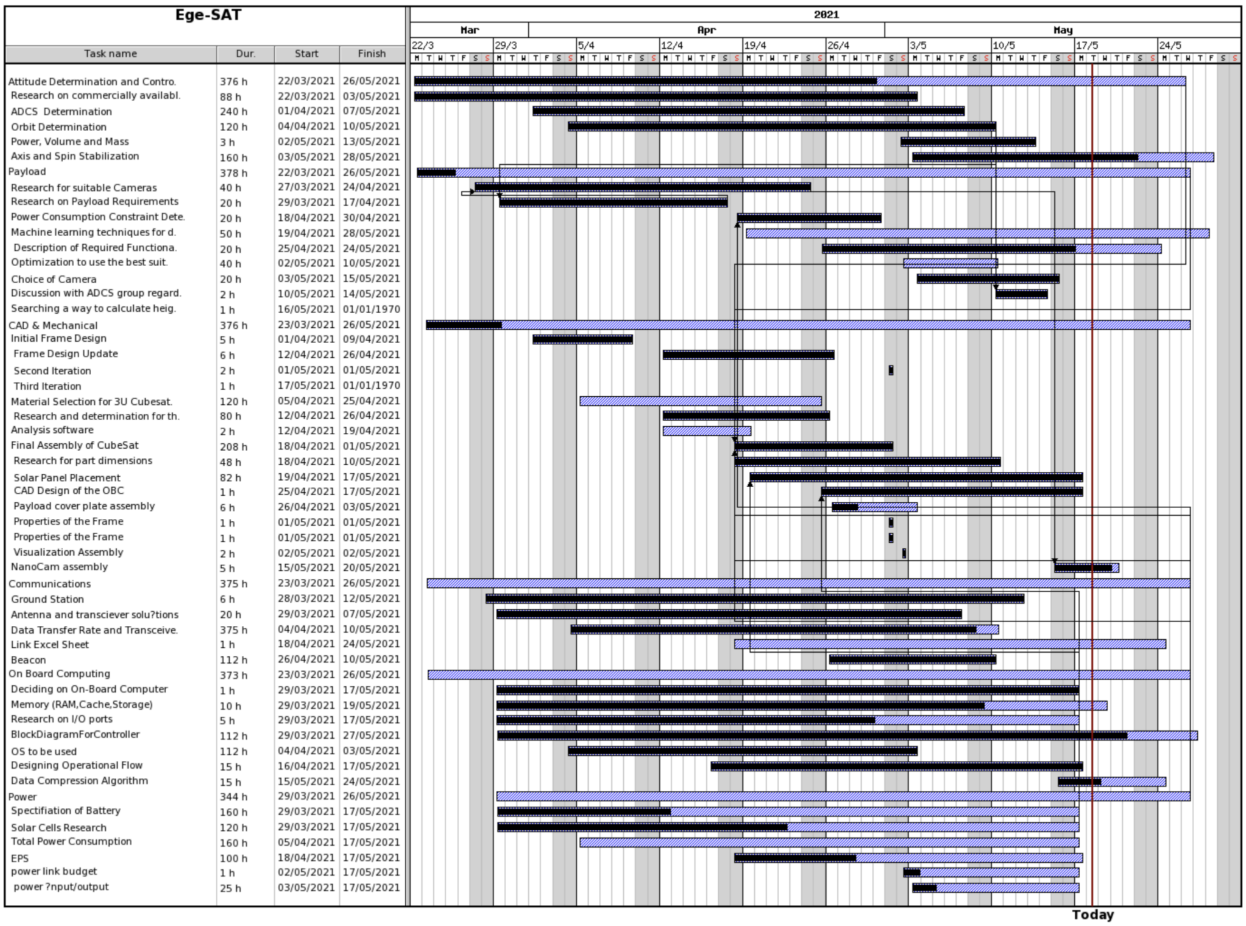
Ege-Sat will monitor the Aegean region of Turkey for six years and will be used to monitor the forest area change over that period of time.

2.2. PROJECT ORGANIZATION SCHEME

POWER	OBC	COMMS	PAYLOAD	ADCS	MECHANICAL
			Mission Critical Research **Imaging research** **Detection Research**	**Research on commercially available ADCS systems and ADCS determination** **Orbit Determination** **Power, Volume and Mass** **Axis and Spin Stabilization**	**3D Modeling of the CubeSat Structure and assembly of the sub-components** **Material research and determination for 3U CubeSat Frame**

			Members: **Yakuphan Emre Kendir** **Selim Kırbıyık** **Özgür İdis** **Bengisu Andiç** **Louaye Mandari**	**Members:** **Coşku Akyüz** **Cem Obuz** **Eliz Doğan** **Berke Deniz Bozyiğit**	**Members:** **Selçuk Mert Günyüz** **Bahadır Patır** **Hamza Hasan** **Raman Akram**

2.3. PROJECT CALENDAR



3. MISSION OVERVIEW

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3.1. Concept of Operations

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3.2. ORBIT

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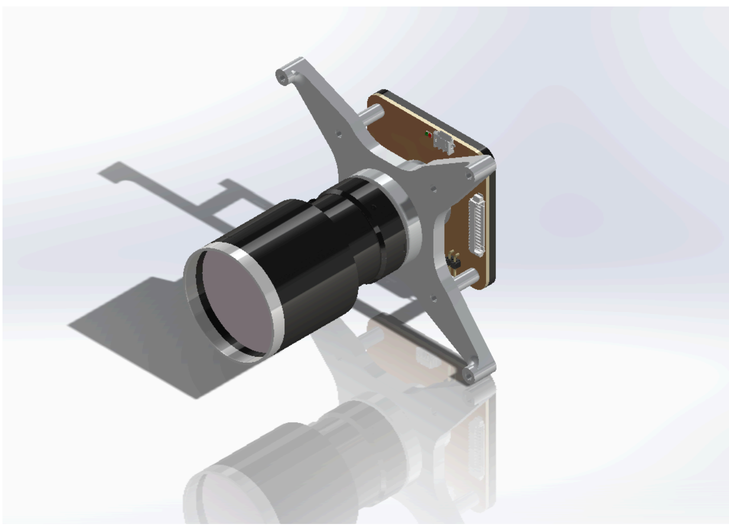
4. PAYLOAD



Nanocam C1U with 70mm lens

The functional requirements of the payload was determined through the need for a resolution enough to input to a machine learning algorithm and get reliable results. From our literature review, we have found that at a 650km Lower Earth Orbit, comparable applications of detection studies used 20 to 30m of GSD. This has been satisfied by the NanoCam C1U adequately, and it is sufficient in terms of mass, volume and power usage. These compliances have been determined by communicating with various departments such as volume requirements with the Mechanical team, and power requirements with the power team.

The absence of experience regarding the Machine Learning Algorithms have pushed us to concentrate on the functionality of the algorithms rather than their application. The forest detection application can be developed while the camera is capturing the images. Thus we have come up with the following criteria for the algorithm.

- Ability to identify forest areas based on their colour properties (Green Areas)
- Observe the change over a period of time
- Record the current forest area and calculate the change over time

Further research with computer vision applications might prove useful for the application of an actual satellite.

4.1 Payload Components

NanoCam C1U

The NanoCam C1U system is a flexible and modular system to rapidly implement tailored imaging systems based on customer requirements. It is an off-the-shelf configuration consisting of: lens, lens table, image acquisition, processing board, and software.
NanoCam C1U has been designed to be implementable in a standard 1U CubeSat structure together with GomSpace's on-board computers, attitude control system, radio transceiver and power products to allow low cost Earth observation using CubeSats.

Highlighted Features of NanoCam C1U

Integrated System:
- Industrial Lens
- 3-megapixel color sensor
- Capable data processing and storage on-board

Image Acquisition:
- 1/2" (4:3) format color CMOS sensor
- 2048 x 1536 pixels
- 10-bit RGB Bayer pattern

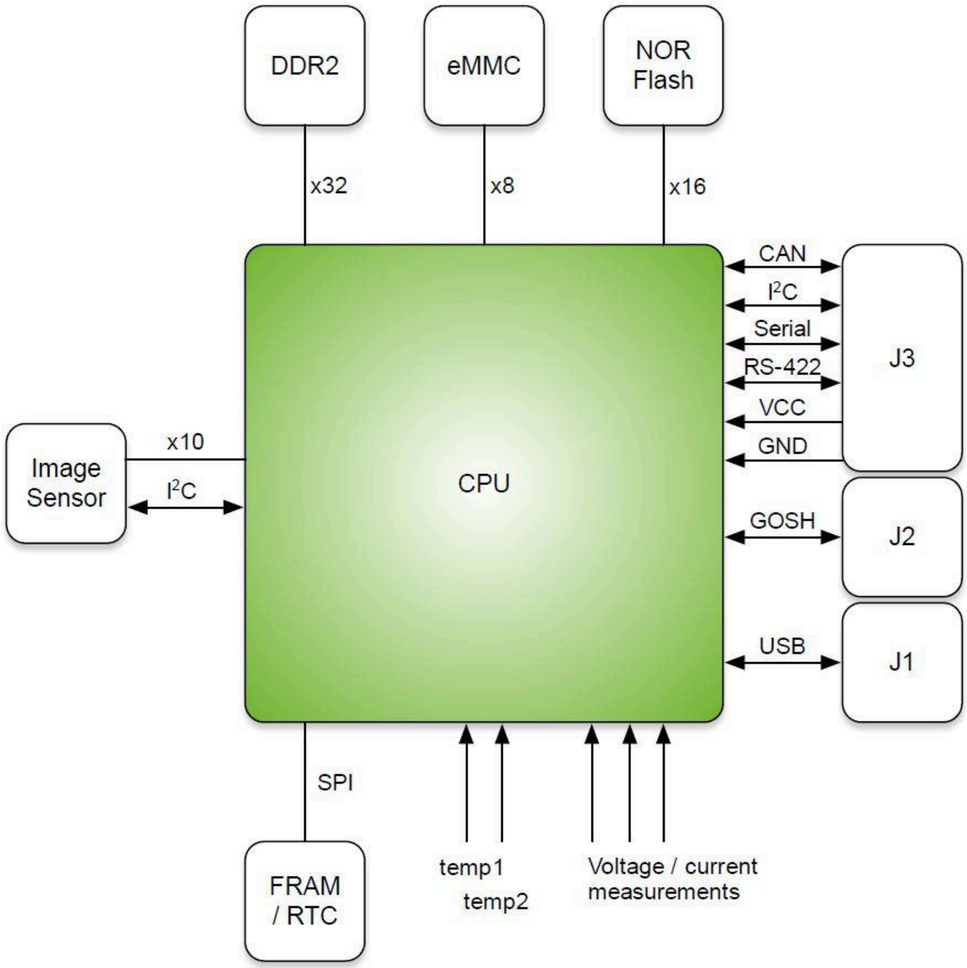
Lens Performance:
- Three high-end industrial lenses
  - 8 mm f/1.4
  - 35 mm f/1.9
  - 70 mm f/2.2
- 8 mm lens: <260 m/pixel from 650 km
- 35 mm lens: <60 m/pixel from 650 km
- 70 mm lens: <30 m/pixel from 650 km
- 400-750 nm spectral transmission

Data Processing:
- High-performance ARM processor
- 512 MB on-board DDR2 RAM
- 2 GB solid state image storage
- RAW, BMP and JPEG output formats

Interface:
- CSP-enabled CAN, I2C, RS-422 and TTL level serial interfaces
- Serial port with text-based console

Quality:

• Glass/Polyimide IPC 6012C cl. 3/A
• IPC-A-610 Class 3 assembly



Block Diagram of NanoCam C1U

Processor
The NanoCam C1U is based on an Atmel SAMA5D35 processor. This is a high-performance, power-efficient ARM Cortex-A5 CPU with an integrated floating-point unit. The NanoCam application runs on a customized embedded Linux platform (GomSpace Linux).

Storage
The board includes 512 MB DDR2 memory for image storage and processing. A 4 GB eMMC flash is used for the root file system and for persistent storage of captured images. 2 GB of the flash is available for image storage. The system boots from a dedicated 64 MB NOR flash attached to the processor's external bus interface.

Image sensor

A key component of the NanoCam is the Aptina MT9T031 digital image sensor. This 1/2“ CMOS sensor produces color images up to 2048x1536 pixels resolution with 10-bit per pixel ADC resolution. It is connected to the main processor with a 10-bit parallel interface for data and I2C for control of image parameters.

F-RAM & RTC

For storage of non-volatile configuration and telemetry data, the C1U board includes a 32 kB Ferroelectric RAM (F-RAM) from Cypress Semiconductor. The stored data is accessible through the GomSpace parameter system. The F-RAM provides virtually unlimited write-erase cycles and also includes a built-in capacitor-backed Real-Time Clock (RTC) that is used to maintain system time across reboots and short periods without power.

Interfaces

The camera is controlled using the Cubesat Space Protocol (CSP) via CAN, I2C, RS-422 or TTL level serial port. Multiple interfaces can be enabled simultaneously to use different interfaces to communicate with different subsystems on the satellite bus.

GOSH

A serial console provides access to operation and debugging commands through the GomSpace shell (GOSH). The serial console also allows access to the standard Linux shell.

Sensors

The NanoCam includes two analog temperature sensors, plus voltage and current sensors on the 3.3 V (VCC), 1.8 V (DDR2) and 1.2 V (CPU) power rails. These values can be read through the parameter system.

Lenses

The C1U is designed to accommodate any lens that conforms to the C-mount interface. It has been tested with the Schneider Optics Industrial Ruggedized 2/3” format lenses. The following features apply to all these lenses:

- 2/3” format
- 11 mm image circle
- 400-750 nm pass band
- Corrected and broadband coated
- Robust metal body
- Precise focusing via fine internal thread
- Unique, robust focus lock
- Click-stop free iris setting / Iris lock
- Integrated front thread to accept SN2 mount filters

The C1U is supplied with a (removable) Schneider Kreuznach BP 540-300 (486) HT UV/IR cut filter, that blocks UV light below 390 nm and IR above 690 nm. Other filter options are available on request.

Absolute Maximum Ratings
Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the C1U. Exposure to absolute maximum rating conditions for extended periods may affect the reliability.

Symbol	Description	Min.	Typ.	Max.	Unit
Tamb	Operating Temperature	0		60	℃
Tstg	Storage Temperature	-40		85	℃
Vio	Voltage on I^’C/serial ports	2.7	3.3	3.6	V

Electrical Characteristics

Symbol	Description	Min.	Typ.	Max.	Unit
Vcc	Supply Voltage	3.2	3.3	3.6	V
I	Supply Current			500	mA

Power Usage

Parameter	Condition	Min	Typical	Max	Unit
Idle			380		mW
Image Acquisition	< 5 s per operation		800		mW
Image Processing	< 10 s per operation		800		mW
System Boot	< 15 s		1300		mW

Physical Characteristics
Mass of system without optics: 77 g

70 mm lens version

Description	Value	Unit
Mass	277	g
Size	86 x 91.7 x 97.2	mm

4.2 Payload Parameter Determination

Our power needs are as follows:

per cycle: 1.6 W
per orbit (100mins): 640W
1 Day: 4.48 kW
1 Week: 31.36 kW
1 Month (31 days): 138.88 kW
1 Year(365 days): 1635.2 kW
25 Years: 40880 kW

As we are only taking a single picture, assuming this only takes 20 mins, ourduty cycle would be around 2%.

Our Data generation will be the following:

Our camera, when configured, can output compressed JPEG format images, an estimation (https://toolstud.io/photo/filesize.php?imagewidth=2048&imageheight=1536) and example given by the manual suggests that a single picture taken at a resolution of 2048x1536 takes up to 0.7 Megabytes (0.65 rounded up) in file size. We are not able to estimate the amount of pictures taken per cycle due to the swath data not available to us. Assuming that we take a single picture each time it becomes the following.

Per orbit: 0.7 MB
1 Day: 4.9 MB
1 Week: 34.3 MB

1 Month (31 Days): 151.9 MB
1 Year (365 Days): 1.7885 GB
6 Years: 10.731 GB

These values are assuming that the cubesat works perfectly throughout its lifetime.

Datasheets:

https://gomspace.com/UserFiles/Subsystems/datasheet/gs-ds-nanocam-c1u-18.pdf

5. EGE-SAT SUBSYSTEMS

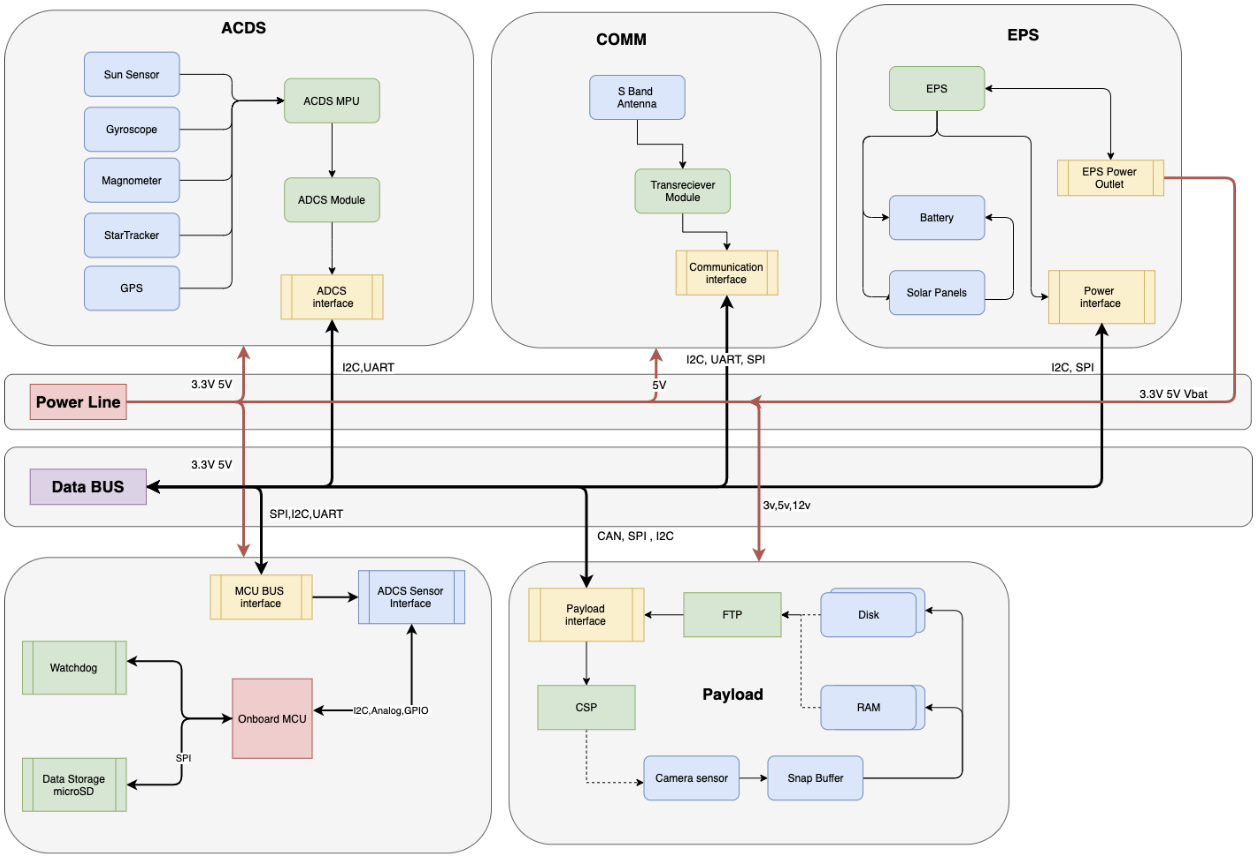
5.1. OVERVIEW

Here we are representing flow charts and diagrams for the On-Board computer. The selected On-Board computer is ISIS On-Board computer and its price is 4.444 euro. Through this document, related numeric values are taken from the following website for the computer:

https://www.isispace.nl/product/on-board-computer/

And in the following subsections, we will be explaining the related diagrams for the computer.

5.2. SYSTEM BLOCK DIAGRAM



5.2.1 Operational Flow Diagram for OBC

5.2.1.1 Operational Flow States

1) **BOOT STATE**

This state is the very first state that the satellite will be in after it settles its orbit. It will be here only for starting operational life and doing necessary checks. Ideally it will never come back to this state unless it faces a fatal error or software update. So, if we decide to upload a software update, it will be in the rebooting state. In addition to that, If the system faces an error that cannot be solved and starts to affect the operations of the system, then with reboot, it may be eliminated, or at least it will give us a chance to develop an update.

2) **IDLE STATE**

This is the state that the system will be in when it is not doing anything. In this state, cube-sat will be waiting for any command to start the action. So, it will try to minimize its power consumption in this state and will wait for any command. The very basic things that the system should check constantly in this state are as follows, Its charge level and the possible received signal.

3) **ADCS STATE**

When the system is in IDLE and receives a signal to start its action first it needs to check its position both for camera and communication systems. If the position is already correct then it can move to the DATA COLLECTING state, if not then the system will be in this state until it's fixed. In that case ADCS mechanisms will fix the rotation of the cubesat to the appropriate position in order to make the payload mission and communication successful. So, OBC will take action with the help of ADCS.

4) DATA COLLECTING

This is the state where the camera will be in active mode. Since the camera position is already checked, the camera is looking to its desired position. So, it can start to take pictures in other terms, it can start to collect data. Two things important in this state: First, the system will start its flow after receiving a signal from the ground state to start collecting data. So, this signal will be sent when the satellite is on the Ege, Turkey. Secondly, since this state comes after the ADCS state, the camera will be directed to the earth to take pictures. During this state, collected data will be written to the memory close to the payload.

5) DATA COMPRESSING

After collecting data, it has to be compressed for sending it to the ground station. So, in this state data will be compressed and will be ready for transfer. After DATA COLLECTING and DATA TRANSFER states are finished, this state will be active. Main memory will be deleted after all compressed data sent to the ground station. So, in this state raw data will be taken from the memory in payload systems and compressed. When the data is compressed it can go to the WRITING STATE to write the transfer-ready data into memory.

6) WRITE STATE

In this state compressed data will be written to the main memory and the raw data in the payload memory will be deleted. This state will work synchronously with the DATA COMPRESSING state. After every compressed data, WRITE STATE will be active and then will go back to the DATA COMPRESSING state until all raw data is compressed to the main memory.

7) DATA TRANSFER STATES

This state will start after GROUND COMMUNICATION state if all checks are OK. During this state the compressed data in the main memory will be transferred to the ground station with communication systems. This state will end either at the end of all data transfer or after the signal from the ground station is lost. After this state, all the compressed data in the main memory will be deleted in order to make room for the new data.

8) GROUND COMMUNICATION STATE
computerfi

After the signal from the ground station is received, this state will be active to start communication. Firstly, system will check if the rotation and position is suitable for a successful communication. If it is not, system will go to ADCS state, fix its position and come back to GROUND COMMUNICATION state. Then, it will check whether the DATA COMPRESSING state is finished or not. If data is fully compressed to the main memory and if there are no other errors, the system will go into DATA TRANSFER STATE.

9) RECHARGE STATE

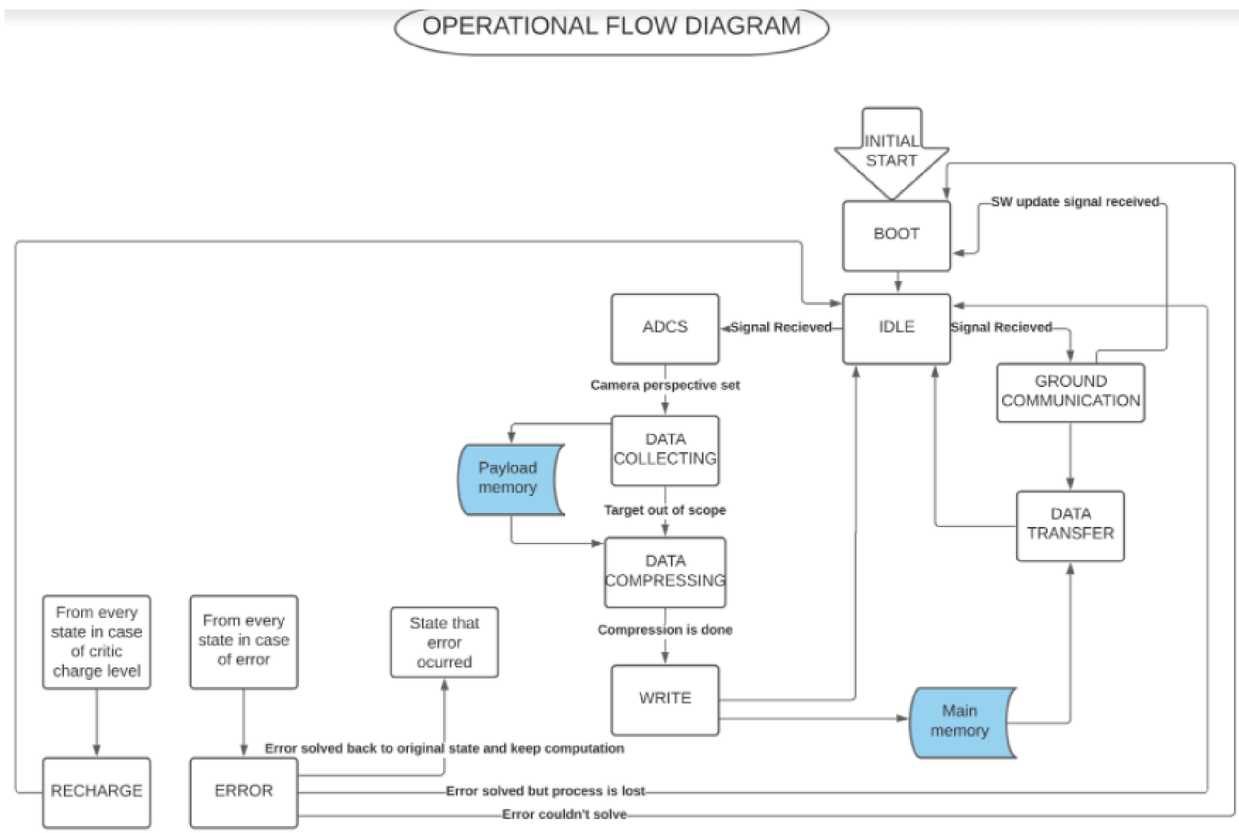
This state is for critical level charge level conditions. This state system holds every computation and process except the crucial ones to stay open. This state will be active when battery level is below the dangerous level and it will maintain until the battery level reaches above the safe levels. And any interrupt requests will not be answered during this state.

10) ERROR & ERROR HANDLING STATE (KERNEL)

In this state, no interruption is possible (except RECHARGE STATE). If the system is in this state, then it means there is an error or exception that OBC has to handle without taking further input. This error can be caused by a microcontroller in the OBC (watched register error or any other reset conditions) or any other errors from other systems. Firstly checks will be made and error handling mechanisms will be active. If the error is still not fixed, the system will wait for a signal from the ground station. If this signal is not received or the signal commands to restart, the system will go to reboot state and restart itself.So, I choose the name kernel because in this state system is not accepting any interruption by the user. So, it is like a kernel in some sense.

5.2.1.1 Operational Flow Diagram

This is the general structure of the operational flow diagram of the onboard computer system in the Ege-Sat.



Detailed version and hierarchical parts of the diagram is given in another file. (https://drive.google.com/file/d/1iFNmJ1jZ2598wWGY1PvWOO-foKQcQcNh/view?usp=sharing)

5.3. OVERVIEW OF EGE-SAT SUBSYSTEMS

5.3.1 Structure

Size: 3U cubesat

Material: 7075-T6 (SN) Aluminum

Total number of parts in the drawing: 2039

Purpose: Structural frame of the CubeSat should meet several requirements such as; offering suitable placement volume for all subcomponents, having enough structural rigidity to withstand mission conditions and meeting the dimensional parameters for 3U CubeSat constraints.

Approximated Parameters:

Mass = 0.72 pounds (Frame weight, excluding internal components)

Total Mass = 3.34 Pounds

Volume = 77.72 cubic inches

Surface area = 1808.22 square inches

Center of mass: (inches)
X = 2.41
Y = 4.96
Z = 8.09

Principal axes of inertia and principal moments of inertia: (pounds * square inches)
Taken at the center of mass.

Ix = (-0.01, 1.00, -0.01)	Px = 10.64
Iy = (-1.00, -0.01, 0.06)	Py = 39.55
Iz = (0.06, 0.01, 1.00)	Pz = 40.02

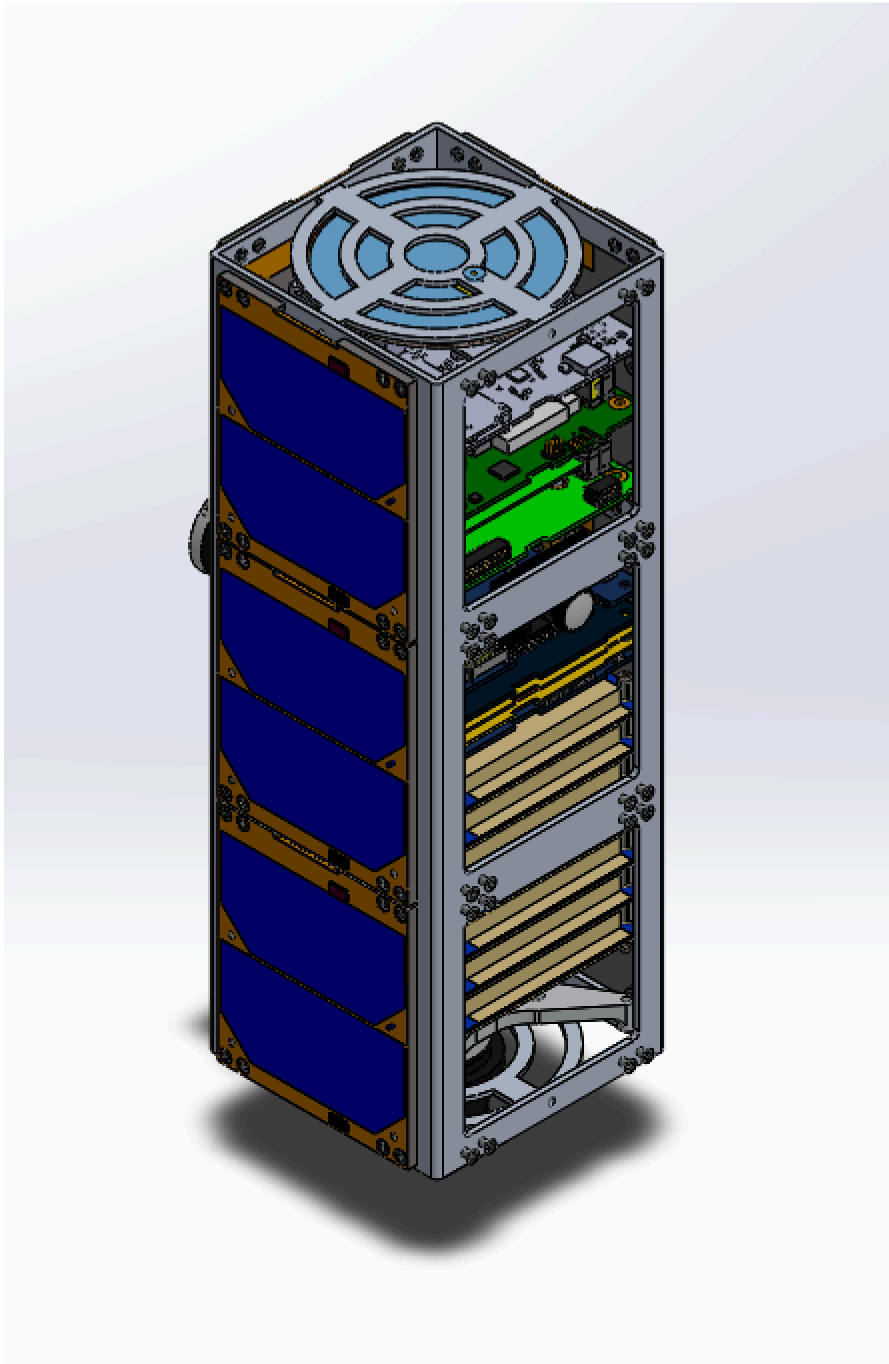
Moments of inertia: (pounds * square inches)
Taken at the center of mass and aligned with the output coordinate system.

Lxx = 39.55	Lxy = -0.24	Lxz = -0.03
Lyx = -0.24	Lyy = 10.65	Lyz = -0.30
Lzx = -0.03	Lzy = -0.30	Lzz = 40.02

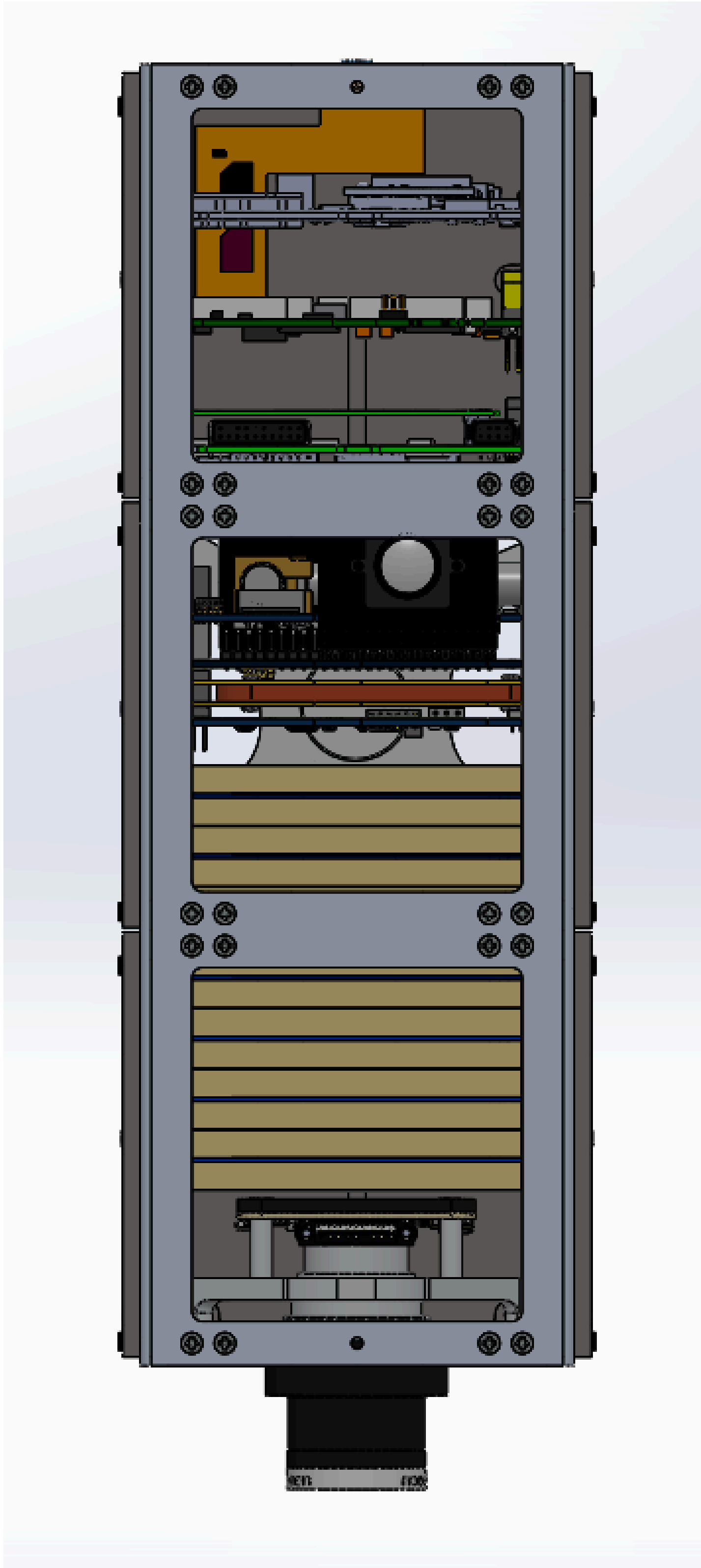
Moments of inertia: (pounds * square inches)
Taken at the output coordinate system.

Ixx = 340.59	Ixy = 39.74	Ixz = 65.12
Iyx = 39.74	Iyy = 248.76	Iyz = 133.89
Izx = 65.12	Izy = 133.89	Izz = 141.76

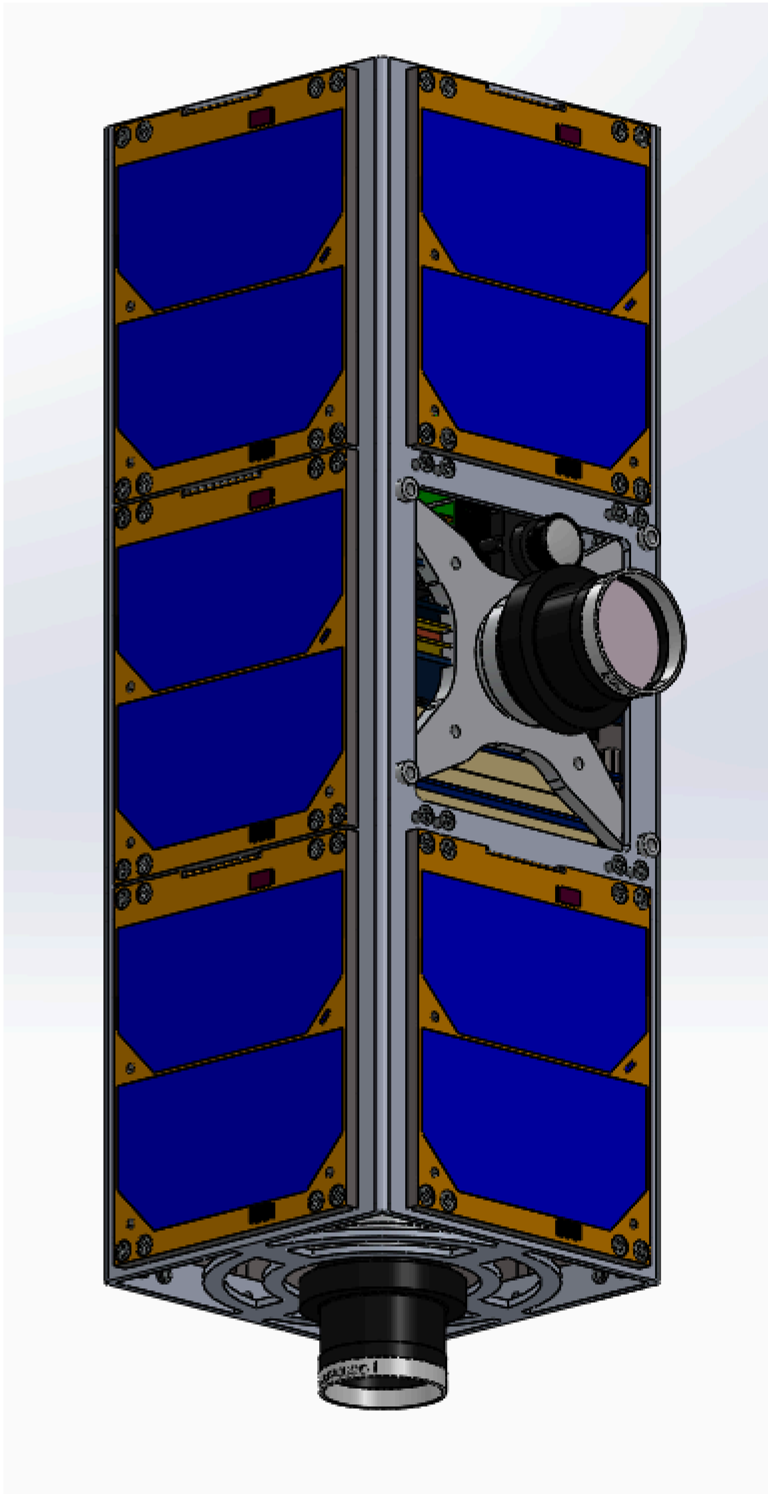
Some pictures of the drawing:

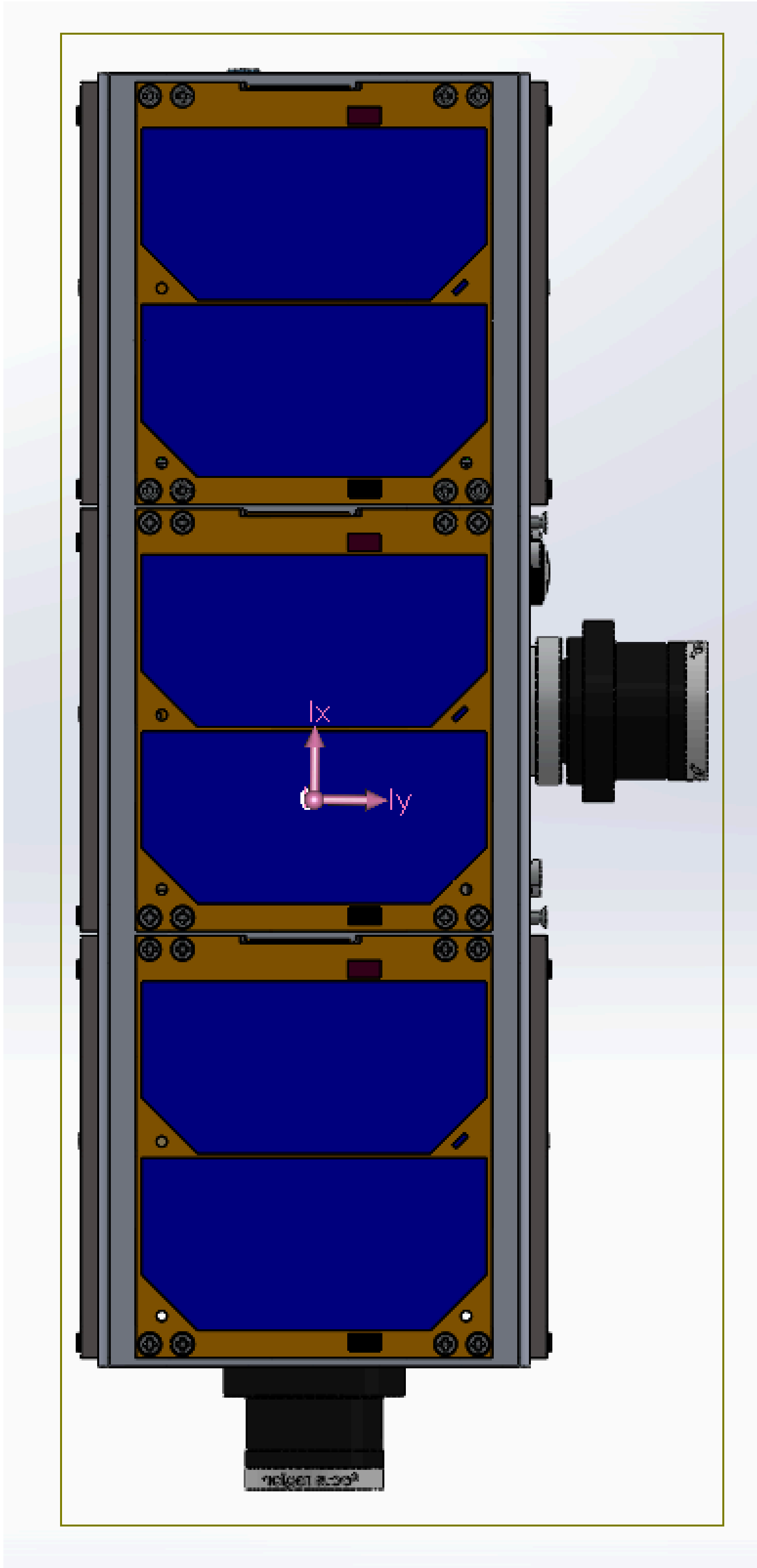


Solar Panels on one side were hidden to reveal the internal components of the satellite.

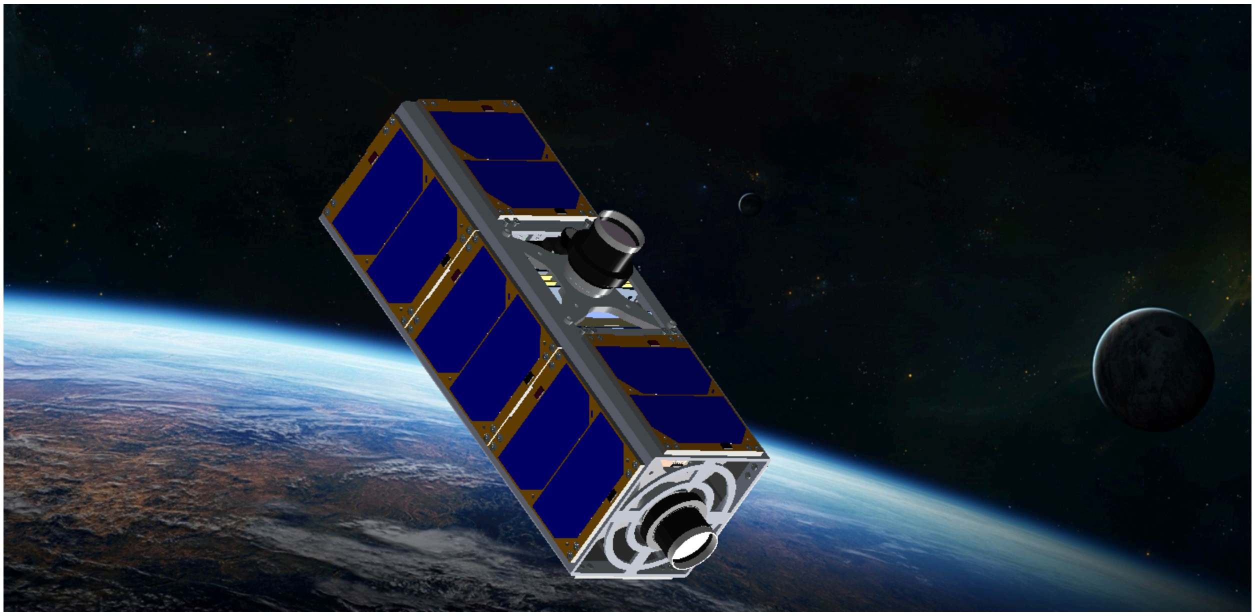


Solar Panels on one side were hidden to reveal the internal components of the satellite.





Center of satellite mass can be seen in this figure (Pink coordinate arrows)



Visualization render of the EGESAT in low earth orbit

Results of the simulations: xxx

5.3.2 Attitude Determination and Control System

Ege-SAT has the CUBEADCS 3-Axis commercially available subsystem. CUBEADCS 3-Axis subsystem achieve a stabilised attitude with 3-axis control. ADCS system has the following characteristics:

- Three reaction wheels are included
- Power consumption: 1.0W(nominal)
- Mass: 506 g
- Operating voltage: 3.3V, 5V battery voltage (7.5V to 16V)
- Dimensions: 90 x 96 x 59 mm
- Operating temp: -10 degC to +60 degC

The system includes NanoCam C1U. Another important aspect of CUBEADCS is that it contains sun sensors. Therefore, it provides high accuracy.

Ege-SAT has been observed for 1 week with the help of satellite tracking software Nova. Elevations under 10 degrees are rejected. Some data related to the communication with the satellite is given as follows:

5/16/2021:
Number of times: 1
Passing Time: 9:26:13
Longest Duration: 0:35:41

5/17/2021:
Number of times: 1
Passing Time: 9:14:42
Longest Duration: 0:35:01

5/18/2021:
Number of times: 1
Passing Time: 9:50:03
Longest Duration: 0:34:11

5/19/2021:
Number of times: 1
Passing Time: 8:55:06
Longest Duration: 0:33:03

5/20/2021:
Number of times: 1
Passing Time: 8:12:56
Longest Duration: 0:31:37

5/21/2021:
Number of times: 1
Passing Time: 7:38:04
Longest Duration: 0:29:44

5/22/2021:
Number of times: 1
Passing Time: 6:51:57
Longest Duration: 0:27:11

As a result, we can communicate with our satellite around 1 times a day with the range of 27:11 – 35:41 minutes.

Parameters:

Semi-major axis(m)= earth radius + orbit= 6378 km+ 650km =7028km=7028000m (sun synchronous orbit, LEO)

Eccentricity: 0.01

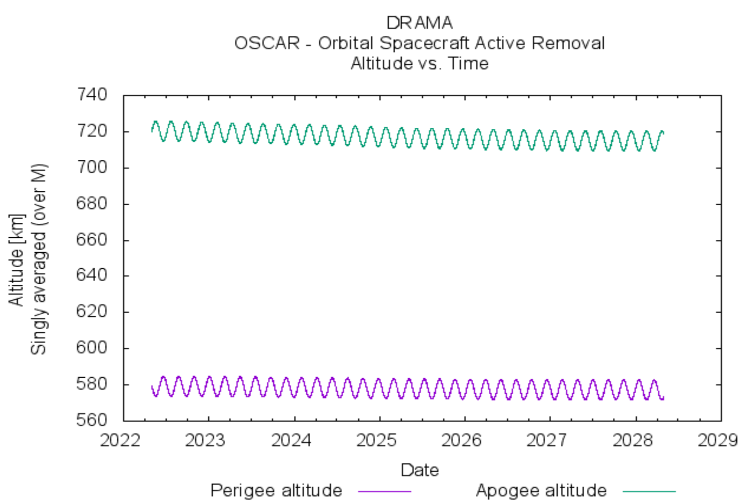
Argument of perigee: 2.36844º

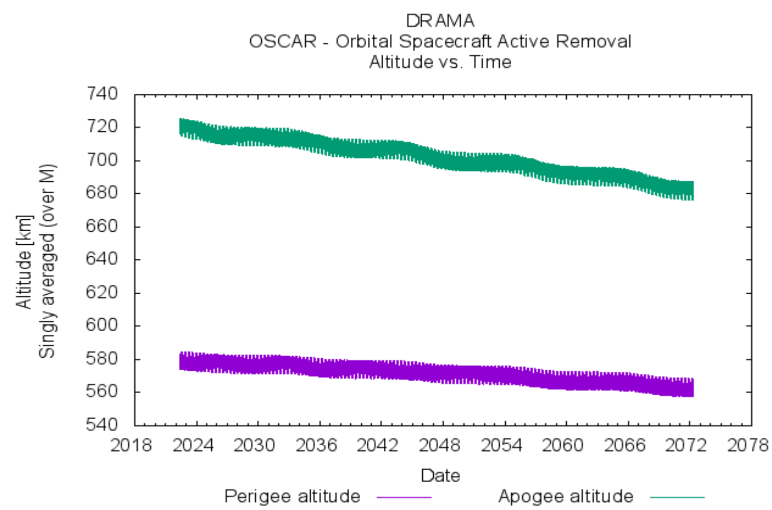
Right ascension of ascending node: 219.221º

Inclination: 44.5º

Mean anomaly: 115.958º

Earth rotation angel: 320.968º





5.3.3 Electrical Power System

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5.3.3.1 Power management

Chosen EPS:

Cost:2.500 Euro
Input Channels :3 (one for each CubeSat axis)
Input Voltage :(Per Solar Panel Channel) up to 5.5 V
Input Current :(Per Solar Panel Channel) up to 1.8 A

Battery Pack Power : 10.2 Wh (20.4 Wh with EPS I Plus)
Battery Pack Voltage: 3.7 V nominal
Mass: 208 g
Output Power Buses: 3.3 V, 5 V, BCR (5 V max) and Battery raw

5.3.3.2 Battery

Supply Voltage: 3.7V nominal , 4.2V at full charge
Supply Current: 1500mAh per cell (multiply by the number of cells in the array)
Typical internal resistance: 1 to 7 milliohms @ 25°C
High discharge rate: 20 times the nominal capacity within 2 seconds
High-speed charge rate: 3 times the nominal capacity

Pegasus Class BA01/S, 22.2 Whr / 6000 mAh, 3.7 V, 89x95x7 mm (LxWxH), 4 Cells
Pegasus Class BA01/D, 44.4 Whr / 12000 mAh, 3.7 V, 89x95x14 mm (LxWxH), 8 Cells
Mass (exact mass depends on configuration):
Pegasus Class BA01/S, 22.2 Whr – 115 grams
Pegasus Class BA01/D, 44.4 Whr – 180 grams

Operating Temperature:

30 to +80°C w/o CN/TTB option

60 to +120°C with CN/TTB option

Radiation Tolerance: 2 years minimum in LEO, 4 years minimum when the S/C has NEMEA shielding

Base panel: FR4-Tg170

Shielding: Optional integrated Carbon Nanotubes Thermal Transfer Bus (CN/TTB) shield

Cell Material: Lithium polymer

Cell Interconnector: Invar Silver plated copper

Interfaces:

Custom choice, normally Molex PicoBlade/PicoSpox inline 2 pin/4 pin connector with gold plated contacts or SAMTEC multi pin gold coated interface

PTFE (Teflon) space grade cables, multi strand, silver plated copper (AWG22 to AWG24)

Power Budget: XYZ -Sat 2005 April 2 Version: 3.1

Parameter:	*Value:*	*Units:*	*Comments:*	
Solar Cell Size (Area):	30.00	cm²	1.975 cm X 2.025 cm Cell	
Solar Cells Per String Per Spacecraft Side:	22			
Parallel Strings Per Side (Facet):	1			
Solar Cell Efficiency at Reference Temperature:	30.00%		Reference: Solar Cell Radiation Hdbk.	
Reference Temperature:	40.00	C°		Add Efficiency vs. Temp. Dependency
Power Per String (0 deg. Beta Angle):	26.79	watts	Sun Normal to Facet; One Panel per Facet	
Power Per Spacecraft Side (Facet):	26.79	watts	Sun Normal to Facet; One Panel per Facet	
Sunlite Spacecraft Power:				
Minimum:	26.79	watts	Sun Normal to One Facet; One Panel per Facet	
Typical:	37.89	watts	Sun in X-Y Plane; Equal Illumination of 2 Facets	
Maximum:	58.95	watts	Sun on One Vertex	
Average Sunlit Power:	**41.21**	watts	1/3x(Min+Typ+Max)	Improve This Estimate
Orbit Properties:				
Semimajor Axis:	7028.00	km		
Eccentricity:	0.010			
Inclination:	44.50	deg.		
Period:	97.724	minutes		
Sunlit Orbit Fraction:	0.65			
Orbit Average Power:	**26.62**	watts		
Solar Array Orbit Average Energy Output:	**2601.49**	watt-min.		156.089 kjoules

Energy Summary:	*watt-minutes*		*watt-hours*		*joules*		
Sunlit Minutes per Orbit:	63.13	min.					
Eclipse Minutes per Orbit:	34.59	min.					
Energy Generated per Orbit:	2601.49	watt-min.	43.36	watt-hrs	156,089	joules	
Energy Consumed by Loads per Orbit:	1810.91	watt-min.	30.18	watt-hrs	108,655	joules	
Energy Available to Recharge Battery:	790.58	watt-min.	13.18	watt-hrs	47,435	joules	Per Orbit
Energy Stored in Battery (100% S.O.C.):	**1321.20**	watt-min.	22.02	watt-hrs	79,272	joules	
Energy Drawn from Battery During One Eclipse:	641.06	watt-min.	10.68	watt-hrs			
Capacity Drawn from Battery During One Eclipse:	96.26	amp-min.	**1.60**	amp-hrs			Average Discharge Voltage Estimated - Improve Estimate
Battery Depth of Drain After One Eclipse:	**53.5%**						
Energy Required to Recharge Battery (per Orbit):	754.19	watt-min.	12.57	watt-hrs			Considering Battery Charge Efficiency
Energy Generated Per Minute for Recharging:	12.52	watt-min./min.					
Time Required to Recharge Battery After E.O.E.:	**60.22**	minutes	Must Be < Sunlit Minutes				This Value Cannot Exceed Sunlit Minutes per Orbit
		= Positive Power Budget					
		= Negative Power Budget					
Orbits before Battery Depletion at Current Discharge Rate:	Unlimited Orbits						

Loads, Regulators, Batteries, Solar Cells: XYZ -Sat 2005 April 2 Version: 3.1

Load Characteristics: Component:	Current: Direct from BAT(10.0V):		Current: +5V Regulator:		Current: +3.3V Reg.:		Orbit Average Duty Factor:	Peak Sub-system Power:	Units:	Average Sub-system Power:	Units:	Orbit Average Energy:		Orbit Average Energy (Joules):	
Flight Computer:	0	amps	0	amps	0.91	amps	100%	3.00	watts	3.00	watts	293.5	watt-minutes	17,608	joules
Command/Data Receiver:	0	amps	0.15	amps	0.3	amps	100%	1.74	watts	1.74	watts	170.0	watt-minutes	10,202	joules
Telemetry/Data Transmitter:	0	amps	0.05	amps	4	amps	50%	13.45	watts	6.73	watts	657.2	watt-minutes	39,432	joules
Experiment #1 (Camera):	0	amps	0.330	amps	0.5	amps	2%	3.30	watts	0.07	watts	6.4	watt-minutes	387	joules
Attitude Control System:	0	amps	0.5	amps	0.9	amps	50%	5.47	watts	2.74	watts	19221.6	watt-minutes	1,153,295	joules
Total Output Power/Energy Per Regulator:	0.00	watts	5.15	watts	21.81	watts		**26.96**	watts	**14.27**	watts	**20348.7**	watt-minutes	1,220,924	joules
Total Input Power/Energy Per Regulator:	0.00	watts	6.50	watts	28.51	watts		**35.02**	watts	**18.53**	watts	**1810.9**	watt-minutes	108,655	joules

Power Regulator and Battery Efficiencies:	Unit:
Battery Charge Regulator Efficiency:	90%
+5V Regulator Efficiency:	88%
+3.3V Regulator Efficiency:	85%
Battery Charge Efficiency:	85%

5.3.3.3 Solar panels

ISISPACE Tecnologies 2U solar panels are used.Power Delivered:

Battery Characteristics:	Unit:		
Technology:	Lipo		
Battery Cells in Series String:	2.00	Cells	
Parallel Strings:	1.00	String(s)	
Battery Operating Temperature:	60.00	deg. C	
Battery Temperature Coefficient:	-0.0027	V/Cell/deg. C	Apply Temp. Coeff. to Cell Potentials Below
Cell Voltage (Fully Charged; Under Load):	4.00	V/Cell	
Cell Voltage (Typical Operating Cond.; Under Load):	3.33	V/Cell	
Cell Voltage (At Lowest S.O.C. Limit):	3.34	V/Cell	
Cell Votage (Fully Charged; Under Trickle Ch):	4.00	V/Cell	
Battery Cell Capacity:	3.0	amp-hrs	Capacity = **C**
Battery Safe Trickle Charge Rate	0.1	amps	C/30
Battery Voltage (Fully Charged; Under Load):	8	V	
Battery Voltage (At Lowest S.O.C. Limit):	6.68	V	
Battery Voltage (Fully Charged; Under Trickle Ch):	8.00	V	
Battery Voltage (Typical @ 20 deg.C):	6.66	V	
Battery Capacity:	3.00	Amp-Hrs	
Battery Reference Temperature:	60.00	deg. C	
Total Battery Energy	1321.20	watt-min.	22.02 watt-hrs

Solar Cell Characteristics:	Parameter:		Comments:
Solar Cell Technology:	GaAsGe		
Solar Cell Dimension A:	60	mm	Reference Cell
Solar Cell Dimension B:	50	mm	Reference Cell
Solar Cell Area:	30.000	cm²	
Solar Cell Short Circuit Current Density:	0.0300	amps/cm^2	Solar Cell Radiation Handbook, July 1, 1996, p 6-35
Solar Cell Short Circuit Current (Isc):	0.900	amps	
Solar Cell Open Circuit Voltage (V_{oc}):	0.998	volts	Solar Cell Radiation Handbook, July 1, 1996, p 6-35
Solar Cell Voltage at Max. Power (V_{mp}):	0.842	volts	Solar Cell Radiation Handbook, July 1, 1996, p 6-36
Solar Cell Current Density at Max. Power:	0.025	amps/cm^2	Solar Cell Radiation Handbook, July 1, 1996, p 6-36
Solar Cell Current at Max. Power (Imp):	0.744	amps	
Solar Cell Max. Power Output (Power Knee):	0.093	watts	Solar Cell Radiation Handbook, July 1, 1996, p 6-37
Solar Cell Efficiency:	30.00%		Solar Cell Radiation Handbook, July 1, 1996, p 6-38
Solar Cell Reference Temperature:	40.0	deg. C	All Cell Parameters Referenced to this Temp. and 1 Solar Constant (AM0)
Solar Array, Series Cells per String:	22	Cells	20 Cells per Series String
Solar Array, Parallel Strings per Panel:	1	String(s)	1 String per Panel
Solar Array Voltage at P_{max}:	18.53	volts	Sun Normal to Array, 28 deg. C
Solar Array Current at P_{max}::	0.744	amps	Sun Normal to Array, 28 deg. C
Solar Array Maximum Power:	13.783	watts	Sun Normal to Array, 28 deg. C

2U: 4.6 W

Supply Voltage: 3V (5V and 8V on demand)

Cell Material: GaAs
Cell Efficiency: 30%
This solar panel system has 30cm2 cells per 2U sides and we are covering 4 sides of our satellite adding up to 660 cm2 of solar cell area.

5.3.4 Command and Data Handling System

5.3.5 Communication System

5.3.5.1. Operating Frequency and Antenna Specifications

We considered 3 possible frequency bands VHF(Very High Frequency), UHF(Ultra High Frequency) and S-Band. After consideration of the data rate that needs to be transferred S-Band was decided as our frequency band. We have decided that the cubesat will operate in frequency range of 2025-2200 MHz.

We have done our research and we have concluded on using ISISPACE S-band transceiver and patch antenna.

RF Configuration: We have chosen to use a single monopole antenna for our application which will operate in between 2025-2200 MHz.

/*

Preliminary Tuning Structure Size: 2U

Mounting Position: Top of the cubesat

Do you have other Deployable systems in your satellite?: No

Supply Voltage: 3.3V

MicroController Interface: I2C (Single Bus)

Primary I2C address3: Default(0x31)

Redundant I2C address: Default(0x32)

Are you using a Pumpkin Structure ?: No

Is the Harness set required?: No */

The ISIS S-Band patch antenna:
https://www.isispace.nl/product/s-band-patch-antenna/

Datasheet for antenna:
[DATASHEET (isispace.nl)]

The ISIS S-Band transceiver:
[CubeSat S-band Transceiver - ISISPACE]

5.3.5.2. Data Transfer Rate

In this mission, basically, we will take pictures from space (in LEO) and send them back to the ground. In general, there are two aspects of it. First one, we should find an appropriate transceiver that can hold transferring relatively high resolution images. Second one, since this transfer process takes place in a certain amount of time interval, we should take into consideration data transfer rate as well. Then according to these, we can determine the duty cycle so that we can know when our system should be transferred information.

First of all we determined which protocol we should use. It is important because it is directly related to data transfer rate. There are two protocols that can be used in cube-sat missions. AX.25 is one of the most common protocols implemented in cube-sat missions which makes it an appropriate choice to use as a base in this investigation. Another protocol is FX.25. Basically, FX.25 is an improved version of AX.25 by providing Forward Error Correction (FEC) capabilities. Let's try to investigate more detaily.

AX.25:

Flag	Address	Control	Info	FCS	Flag
01111110	112/224 bits	8/16 bits	N*8 bits	16 bits	01111110

(a) AX.25 U and S frame construction. Adapted from Ref. [10].

Flag	Address	Control	PID	Info	FCS	Flag
01111110	112/224 bits	8/16 bits	8 bits	N*8 bits	16 bits	01111110

(b) AX.25 I frame construction. Adapted from Ref. [10].

1. **Flag Field:**

The flag field is placed at the beginning and at the end of the construction. They are one byte length. The flag field's binary sequence is '0111110' (0x7E). This pattern should not be repeated in any frame because it is reserved for just flags.

2. **Address Field:**

Address Field	
Destination Address Subfield	Source Address Subfield
A1 A2 A3 A4 A5 A6 A7	A8 A9 A10 A11 A12 A13 A14

A1	Call Sign	A8	Call Sign
A2	Call Sign	A9	Call Sign
A3	Call Sign	A10	Call Sign
A4	Call Sign	A11	Call Sign
A5	Call Sign	A12	Call Sign
A6	Call Sign	A13	Call Sign
A7	CRRSSID0	A14	CRRSSID1

The address field contains the source and destination address of the specific frame

3. **Control Field:**

The control field identifies which type of frame is being sent or received.

4. **PID Field:**

The Protocol Identifier Field (PID) identifies what protocol, if any, is running on top of the AX.25 layer.

5. **Info Field:**The info field carries user data. This field defaults to 256 bytes.

6. **FCS Field:**

The FCS is a 16-bit value that is calculated by the transmitter and receiver, to determine if a frame has been corrupted during transmission.

(This information was taken from "*Development of a Satellite Network Simulator Tool and Simulation of AX.25, FX.25 and a Hybrid Protocol for Nano-Satellite Communications by Jan-Hielke Le Roux*".
More detailed information about field can be found in that resource)

Since the ADCS team decided to place our cubesat in Low Earth Orbit, we should take into consideration the following. LEO leads to short ground station access time and as can be understood from the previous part, full AX.25 stack comes with some overhead. Therefore, *Jan-Hielke Le Roux* says that, *"*A sub-set of AX.25 is often implemented on nano-satellite missions to reduce complexity and overhead. This subset is known as 'connectionless AX.25'. In this mode, the AX.25 protocol operates in a connectionless manner, where data can be exchanged between nodes without any prior arrangement or configuration of a network link." To be more specific, 'connectionless AX.25' means UI frame which is the following;

Flag	Address	Control	PID	Info	FCS	Flag
01111110	112/224 bits	00000011	11110000	N*8 bits	16 bits	01111110

Figure 4.9 – Connectionless AX.25 UI Frame.

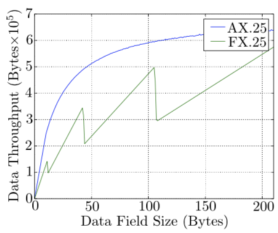
FX.25:

In AX.25 we can lose a frame because of a single bit error. Actually because of that drawback, FX.25 was implemented as AX.25 with FEC.

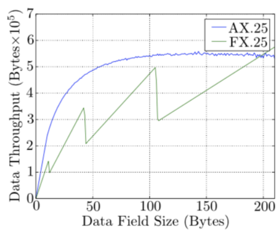
Preamble	Correlation Tag	AX.25 Packet Start	AX.25 Packet Body	AX.25 Packet FCS	AX.25 Packet End	Padding	FEC Check Symbols	Postamble
		FEC Code Block						

As can be seen from the structure, with using FX.25 we can encounter much more overhead compared to AX.25. Since even complete AX.25 implementation can cause a problem because of short ground station access time, FX.25 can cause much more problems in terms of transferring high resolution images in a short period of time. Also, we can obtain noisy, blurry, cloudy images, because of that we should take as many photographs as possible and send them to the ground. Therefore, I think we don't need to go into detail about FX.25. As I mentioned before, more detailed information can be obtained from *Development of a Satellite Network Simulator Tool and Simulation of AX.25, FX.25 and a Hybrid Protocol for Nano-Satellite Communications by Jan-Hielke Le Roux.*

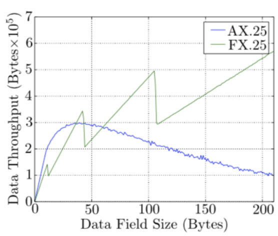
Last but not least, *Development of a Satellite Network Simulator Tool and Simulation of AX.25, FX.25 and a Hybrid Protocol for Nano-Satellite Communications by Jan-Hielke Le Roux* has very good simulation results which compares AX.25 and FX.25 protocols in several aspects.



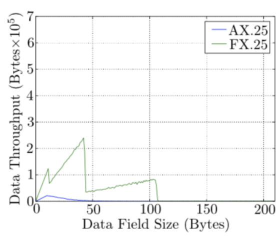
(a) Constant 10^{-5} BER channel.



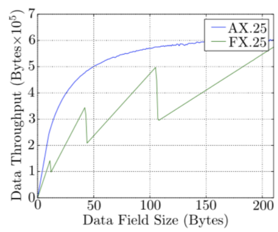
(b) Constant 10^{-4} BER channel.



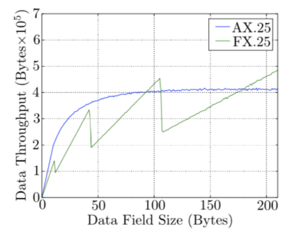
(c) Constant 10^{-3} BER channel.



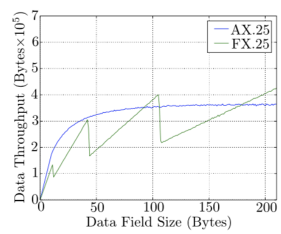
(d) Constant 10^{-2} BER channel.



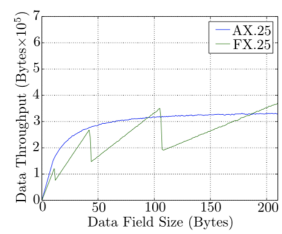
(a) 0 dB antenna gain.



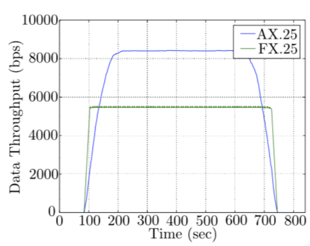
(b) -3 dB antenna gain.



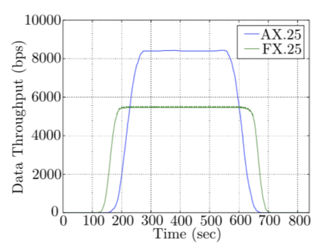
(c) -4 dB antenna gain.



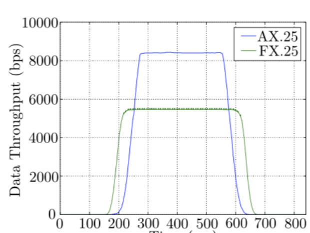
(d) -5 dB antenna gain.



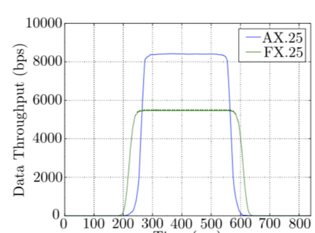
(a) 0 dB antenna gain.



(b) -3 dB antenna gain.



(c) -4 dB antenna gain.



(d) -5 dB antenna gain.

As can be seen in the simulation results AX.25 is a better option for us because of higher Data Throughput.

Additionally *Jan-Hielke Le Roux's* opinion about this results are worth to mention:

- "AX.25 gets more data through when the satellite is closer to the ground station."
- "FX.25 is able to transfer data in the early stages of the satellite pass with reduced signal gain, where AX.25 is unable to. AX.25 has a much higher throughput when it is closer to the ground station, as it carries less overhead data compared to FX.25."

Satellite	Object	Size	Radio	Frequency	License	Power	TNC	Protocol	Baud Rate/Modulation	Downloaded	Lifetime	Antenna
AAU1 CubeSat	27846	1U	Wood & Douglas SX450	437.475 MHz	amateur	500 mW	MX909	AX.25, Mobitex	9600 baud GMSK	1 kB	3 months	dipole
DTUsat-1	27842	1U	RFMD RF2905	437.475 MHz	amateur	400 mW		AX.25	2400 baud FSK	0[1]	0 days	canted turnstile
CanX-1	27847	1U	Melexis	437.880 MHz	amateur	500 mW		Custom	1200 baud MSK	0[1]	0 days	crossed dipoles
Cute-1	27844	1U	Maki Denki (Beacon)	436.8375 MHz	amateur	100 mW	PIC16LC73A	CW	50 WPM	N/A	65+ months	monopole
(CO-55)			Alinco DJ-C4 (Data)	437.470 MHz	amateur	350 mW	MX614	AX.25	1200 baud AFSK	>10 MB		monopole
QuakeSat-1	27845	3U	Tekk KS-960	436.675 MHz	amateur	2 W	BayPac BP-96A	AX.25[2]	9600 baud FSK	423 MB	7 months	turnstile
XI-IV	27848	1U	Nishi RF Lab (Beacon)	436.8475 MHz	amateur	80 mW	PIC16C716	CW	50 WPM	N/A	65+ months	dipole
(CO-57)			Nishi RF Lab (Data)	437.490 MHz	amateur	1 W	PIC16C622	AX.25	1200 baud AFSK	>11 MB		dipole
XI-V	28895	1U	Nishi RF Lab (Beacon)	437.465 MHz	amateur	80 mW	PIC16C716	CW	50 WPM	N/A	36+ months	dipole
(CO-58)			Nishi RF Lab (Data)	437.345 MHz	amateur	1 W	PIC16C622	AX.25	1200 baud AFSK			dipole
NCube-2	28897[3]	1U		437.505 MHz	amateur			AX.25	1200 baud AFSK	0[1]	0 days	monopole
UWE-1	28892	1U	PR430	437.505 MHz	amateur	1 W	H8S/2674R[4]	AX.25	1200/9600 baud AFSK		0.75 months	end-fed dipole
Cute-1.7+APD	28941	2U	Telemetry Beacon	437.385 MHz	amateur	100 mW	H8S/2328[4]	CW	50 WPM	N/A	2.5 months	dipole
(CO-56)			Alinco DJ-C5	437.505 MHz	amateur	300 mW	CMX589A	AX.25/SRLL	1200 AFSK/9600 GMSK	<1 MB		dipole
GeneSat-1	29655	3U+	Atmel ATA8402 (Beacon)	437.067 MHz	amateur	500 mW	PIC12C617	AX.25	1200 baud AFSK	N/A	3 months	monopole
			Microhard MHX-2400	2.4 GHz	ISM	1 W	Integrated[5]	Proprietary		500 kB		patch
CSTB1	31122	1U	Commercial[6]	400.0375 MHz	Experimental	<1 W	PIC	Proprietary	1200 baud AFSK	6.77 MB[7]	19+ months	dipole
AeroCube-2	31133	1U	Commercial[6]	902-928 MHz	ISM	2 W	Integrated[5]	Proprietary	38.4 kbaud	500 kB	0.25 months	patch
CP4	31132	1U	TI CC1000	437.325 MHz	amateur	1 W	PIC18LF6720	AX.25	1200 baud FSK	487 kB	2 months	dipole
Libertad-1	31128	1U	Stensat	437.405 MHz	amateur	400 mW		AX.25	1200 baud AFSK	0[8]	1 month	monopole
CAPE1	31130	1U	TI CC1020	435.245 MHz	amateur	1 W	PIC16LF452	AX.25	9600 baud FSK	0[9]	4 months	dipole
CP3	31129	1U	TI CC1000	436.845 MHz	Experimental	1 W	PIC18LF6720	AX.25	1200 baud FSK	2.0 MB[7]	19+ months	dipole
MAST[10]	31126	3U	Microhard MHX-2400	2.4 GHz	ISM	1 W	Intgrated[5]	Proprietary	15 kbps	>2 MB	0.75 months	monopole
Delfi-C3	32789	3U	Custom Beacon	145.870 MHz	amateur	400 mW	PIC18LF4680	AX.25	1200 baud BPSK	60 MB[11]	7+ months	turnstile
(DO-64)			Custom Transponder	145.9-435.55 MHz	amateur	200 mW	N/A	Linear	40 kHz wide	N/A		turnstile
Seeds-2	32791	1U	Musashino Electric (Beacon)	437.485 MHz	amateur	90 mW		CW		N/A	7+ months	monopole
(CO-66)			Musashino Electric (Data)	437.485 MHz	amateur	450 mW		AX.25	1200 baud AFSK	500 kB		monopole
CanX-2	32790	3U	Custom S-Band	2.2 GHz	Space Research[12]	500 mW	Integrated	NSP	16kbps-256kbps BPSK	250 MB	7+ months	patch
AAUSAT-II	32788	1U	Holger Eckhardt (DF2FQ)	437.425 MHz	amateur	610 mW	PIC18LF6680	AX.25	1200 baud MSK	8 MB[13]	7+ months	dipole
Cute 1.7+APD II	32785	3U+[14]	Invax (Beacon)	437.275 MHz	amateur	100 mW	H8S/2328	CW	50 WPM	N/A	7+ months	monopole
(CO-65)			Alinco DJ-C5 (Data)	437.475 MHz	amateur	300 mW	H8S/2328, CMX589A	AX.25/SRLL	1200 AFSK/9600 GMSK	21 MB[15]		monopole
Compass-1	32787	1U	BC549 (Beacon)	437.275 MHz	amateur	200 mW	PIC12F629	CW	15 WPM	N/A	7+ months	dipole
			Holger Eckhardt (Data)	437.405 MHz	amateur	300 mW	C8051F123, FX614	AX.25	1200 baud AFSK/MSK	<1 MB		dipole

Finally , if we analyze the table, we can see that AX.25 is very commonly used in cubesat projects. Almost in all projects, AX.25 was used. I think this is very important indicator because we can find more resources which can give information about critical parts in protocol implementation, so we can implement our protocol more reliable.

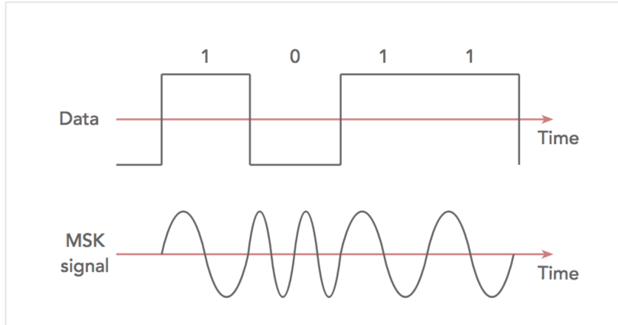
(I want to mention that QuakeSat-1's protocol Source Code is available upon request)

Because of these investigations, using AX.25 as protocol was decided.

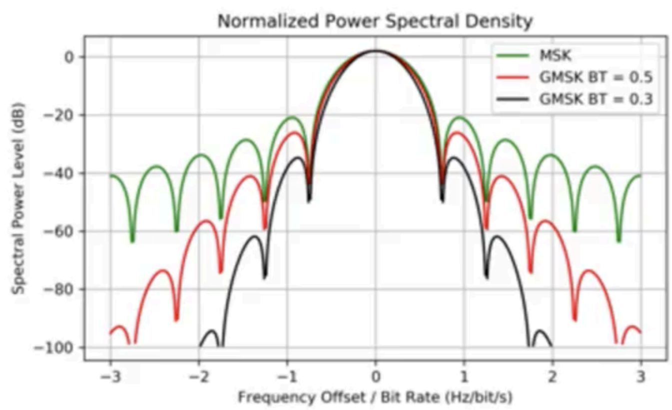
using GMSK was decided;

GMSK:

- In MSK and also GMSK there are no phase discontinuities.
- Improved spectral efficiency when compared to other phase shift keyed modes.
- It can be amplified by a non-linear amplifier and remain undistorted This is because there are no elements of the signal that are carried as amplitude variations
- It suppresses sideband power, hence provides better noise performance.



Concept of a minimum shift keying, MSK signal



Camera was chosen as the NanoCam C1U by the payload team. According to the data sheet, the camera takes pictures with specifications as; 2048 x 1536 pixels and 10-bit RGB Bayer pattern. According to this information we can calculate the size of the image that we take. Firstly we have 3.145.728 pixels in total. Secondly, the camera takes pictures as 10-bit RGB Bayer pattern which means that each of the red, green and blue colors are stored in 10 bits, so this means that we use 30 bits per pixel.

Therefore size of a photo is 3.145.728 * 30 = 94.371.840 bits = 11,79648 MB.

- Additionally we can make images much smaller in size with compression methods.

Since we considered using the AX.25 protocol for data transferring, there exists some overhead which comes from protocol necessities (e.g. flags, control bits etc.). As mentioned in the lecture this overhead is about %20.

We calculate the size of the photo as about 11.8 MB. Our overhead is about %20, this means that if we want to send 11.8 MB images to the ground, this means that we have to send 11.8 + 2.4 = 14.2 MB of information (2.4 MB comes from overhead).

As we saw in the lecture, let's say we can utilize %90 of the channel. Our transceiver can transfer up to 1.25 MB/s (on-air). In the previous log I assumed this transfer rate as 1 MB/s. To be in a safe site, let's make our channel utilization over 1 MB/s. If we do so, our transfer rate will be 0.9 MB/s. Therefore we can send 14.2 MB of information in 15.77 seconds.

As I said earlier, we can make images smaller with compression algorithms. This topic was discussed with the On Board Computer Team and they said that we found algorithms that can compress images lossless between %33 and %66. However, they talked with the ADCS team about compression and the ADCS team said that the camera has its own compression algorithms. Then I found a project which used the modified version of our camera. According to that project, their raw images' size is about 30 MB and the compressed images' size is about 4 MB which means that the NanoCam C1U provides us %86.66 compression ratio. If we consider that ratio;

- Our raw image size is 11.8 MB. If we apply %85 compression, we obtain our compressed image size as 1.8 MB.
- Because of the protocol we have about %20 overhead. This means that we will transfer 1.8 + 0.5 = 2.3 MB (0.5 MB comes from overhead)
- Since we calculate data transfer rate as 0.9 MB, our image can be transferred in 2.5 seconds.
- If we consider this scenario, we will have the capacity to transfer 600 images in a day.

According to the orbit that the ADCS team has decided, our cubesat will be in LEO with period as 1. Alos, we talked with the ADCS team about communication duration. According to their simulation result and our conversation, the duration will be at least about 15 minutes and at most about 35 minutes. Therefore, according to our decision, we can easily complete the operations that we need to do (even if we consider uncompressed images).

Finally, since our cubesat will be in LEO with period as 1 and our communication duration will be about 25-35 minutes, the communication system of our cubesat must be on in that time which we communicate with the ground. Actually,this time is sufficient for us to complete the operations that we need to do but I think we should guarantee ourselves. Therefore we can roughly say that the communication system will be on for about 40 minutes in a period.

References:

- *Development of a Satellite Network Simulator Tool and Simulation of AX.25, FX.25 and a Hybrid Protocol for Nano-Satellite Communications by Jan-Hielke Le Roux.*
- https://www.electronics-notes.com/articles/radio/modulation/what-is-gmsk-gaussian-minimum-shift-keying.php#:~:text=Gaussian%20Minimum%20Shift%20Keying%2C%20GMSK,high%20efficiency%20radio%20power%20amplifiers.
- *A Survey of CubeSat Communication Systems / Bryan Klofas (KF6ZEO), Jason Anderson (KI6GIV)*
- *http://propagation.ece.gatech.edu/ECE6390/project/Sum2015/team4/uploads/5/6/8/9/56891091/lensimagesensingsystemofcube_final_(1).pdf*

6. System Budgets

6.1 Mass budget

6.2 Power budget

6.3 Communication coverage analysis

6.4 Link Budget

As up-link and down-link frequency intervals were determined as 435 – 438 MHz and 145.8 – 146 MHz for UHF – VHF communication, transceiver model choice which was ISISpace's UHF-VHF full duplex transceiver could be done. Thus, all the link budget parameters such as antenna gains and RF output powers were determined with respect to orbital elements and communication devices' capabilities. Link budget calculations were done through AMSAT's Basic Analog Transponder Link Budget excel file.
Transceiver's maximum baud rate is 9600 bps. Bandwidth of a PSK modulated signal is approximately 2 times of the baud rate. Therefore, it can be said that bandwidth is around 20 kHz. Furthermore, transceiver that will be used on the CubeSat has 0.5 Watts RF power output.

Typical parameters for the link budget such as antenna gains, antenna pointing losses and transmissions line losses are taken from other CubeSat projects. Ground station's set up properties were taken from Istanbul Technical University.

Finally, uplink and downlink budgets' SNR ratios are safe to communicate properly.

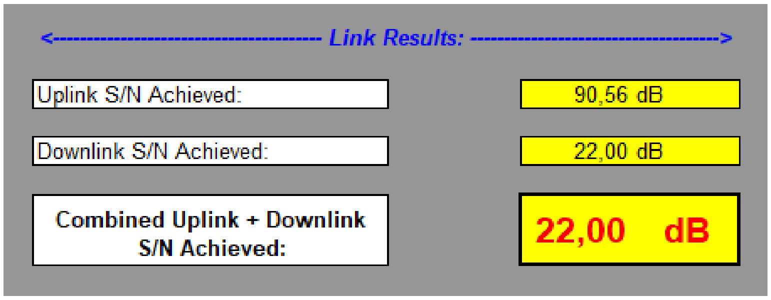
<u>**Calculation Results**</u>

Uplink Budget:

Spacecraft Figure of Merrit (G/T):	-23,2	dB/K	
S/C Signal-to-Noise Power Density (S/No):	78,6	dBHz	Boltzman's Constant: k= -228,6 dBW/K/Hz
Transponder IF Bandwidth:	20,0	kHz	
Transponder Uplink Input Noise Power	-160,8	dBW	P_n = kTB; Additive White Gaussian Noise (AWGN); The satellite receiver's White Noise.
Single User Uplink S/N in Transponder Bandwidth:	35,6	dB	This is the S/N for ONE user seen at the S/C Rcvr IF, measured after the BPF, in the bandwidth determined by that filter.
Transponder Uplink Interference Density:	-250,0	dBW/Hz	This is the interference density seen at the S/C Receiver. Assume Uniform Density Across Transponder Passband.
Transponder Uplink Total Interference Power:	-205,3	dBW	Measured at Spacecraft Receiver Input
Transponder Uplink S/I (Power Ratio):	79,3	dB	This is the ratio of the User signal level compared to the Interference Noise in the entire Transponder Passband
Transponder Total Uplink Noise Power (N+I):	-160,8	dBW	This total noise multiplied by the tranponder's gain will produce wasted output noise power from the HPA.
Single User S(N+I) in Transponder Bandwidth:	79,3	dB	This is the uplink performance measured in the ENTIRE transponder bandwidth (NOTE: This could be a negative number)
Single User Signal Bandwidth:	1,5	kHz	
Single User Uplink S(N+I) in User Terminal Bandwidth:	90,56	dB	THE BOTTOM LINE FOR THE UPLINK (NOTE: This is the average S/(N+I), not the peak value. This matters for SSB

Ground Station Figure of Merrit (G/T):	2,4	dB/K	
G.S. Signal-to-Noise Power Density (S/No):	86,20	dBHz	Boltzman's Constant: -228,6 dBW/K/Hz
Transponder Intermodulation Ratio (S/IM or IMR):	22,0	dB	The ratio of the power in one user signal divided by the average intermodulation power level in one User channel
G.S. Signal-to-Intermodulation Power Density (S/Io)	53,8	dBHz	The Intermodulation Power Density
G.S. S/ (No+Io):	53,76	dBHz	
Single User Signal Bandwidth:	1,5	kHz	
Single User Downlink S/N in User Terminal Bandwidth:	22,00	dB	This is the S/N for ONE user due to downlink thermal noise (AWGN) plus Intermodulation Interference.
			It does not inlude the effects of the uplink noise.

Downlink Budget:



Link Budget Calculations of Other CubeSat Projects

https://paginas.fe.up.pt/~ee97054/Link%20Budget.pdf

https://www.itu.int/en/ITU-R/space/workshops/2016-small-sat/Documents/Link_budget_uvigo.pdf

http://stars.eng.shizuoka.ac.jp/english/STARS_Link_budget.pdf

ISISpace's UHF-VHF Full Duplex Transceiver's Product Information:

https://www.isispace.nl/product/isis-uhf-downlink-vhf-uplink-full-duplex-transceiver

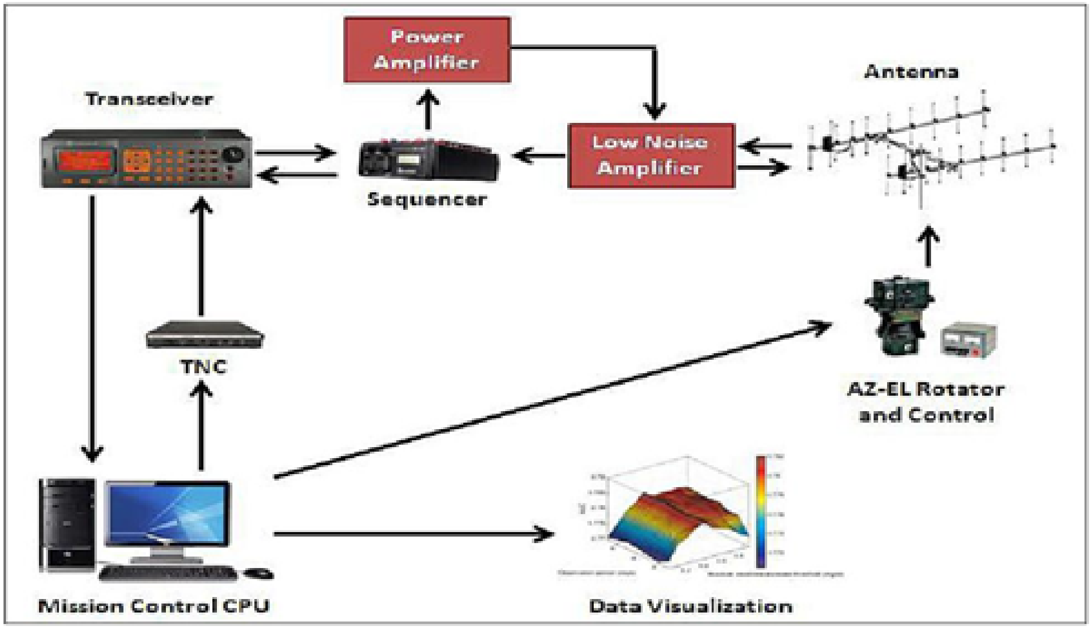
6.5 Cost

- Gumush ; €3000
- ISIS ; €2950 - €3150 (https://www.cubesatshop.com/product/2-unit-cubesat-structure/)
- ISIS; €3150 (https://www.isispace.nl/product/2-unit-long-stack-cubesat-structure/)
- ISIS UHF-VHF Transceiver ; €8500 https://www.isispace.nl/product/isis-uhf-downlink-vhf-uplink-full-duplex-transceiver/
- TMT; €3250 *Information is taken via mail
- Spacemind ; €1970 (https://www.cubesatshop.com/product/2-unit-cubesat-structure/)
- ISIS; €4500 - €5500 (https://www.isispace.nl/product/cubesat-antenna-system-1u-3u/)
- Nanocam C1U; (Not available publicly/By request) (https://gomspace.com/shop/payloads/earth-observation.aspx)

- https://www.cubesatshop.com/product/single-cubesat-solar-panels/ (ISIS CubeSat solar panels) 2U PANEL : 3500 £
- EPS : https://www.endurosat.com/cubesat-store/cubesat-power-modules/eps-power-module/ (EPS1) 3300$
- Battery: https://www.cubesatshop.com/product/ba0x-high-energy-density-battery-array/ (EXA BA0x High Energy Density Battery Array) : 3500£

7. Ground Station

The ground station component relates to actual hardware required to contact the CubeSat, while mission control focuses more on the software needed to operate the mission. We use the ISIS's ground station, which is suitable for a CubeSat mission, usually operates with two controllable Yagi antennas and 2m S-band dish antenna in the VHF, UHF and S bands. There is a rotator which controls azimuth and elevation angles of the antenna with speed up to 6°/sec. S-band and VHF/UHF Ground Station used as a transceiver. It can use HF, 50MHz band, 144 MHz band, 440MHz band and for S band (2200 – 2290 MHz or 2400 – 2450 MHz) . One of the main advantages of this transceiver is a built-in TNC. This TNC conforms to the AX.25 protocol.ISIS ground station has a lightning protection system and also it has an amplifier which is connected to the antenna to boost the signal between antenna and the satellite. There is a wireless modem as in the TNC converts digital data into radio signals at the transmitter and then converts the radio signal back to the digital data at the receiving end.



(Block diagram of the Ground segment)

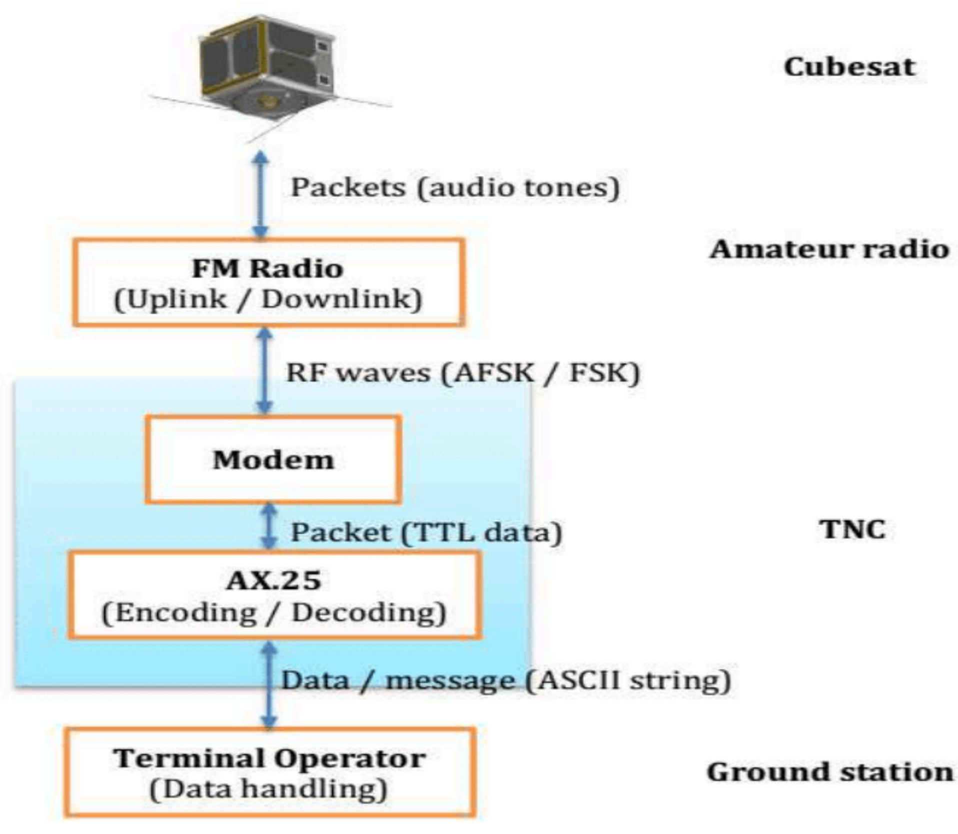
Yagi antenna and 2m S-band dish antenna

Yagi antenna is a directional antenna consisting of multiple parallel elements in a line, usually half-wave dipoles made of metal rods.Yagi antennas consist of a single driven element, a reflector and one or more directors, connected by a transmission line to the transmitter or receiver, and additional interference elements not connected to the transmitter or receiver. The frequency range in which the Yagi-Uda antennas operate is around 30 MHz to 3GHz which belong to the VHF and UHF bands. The bandwidth of a Yagi antenna, the frequency range over which it has high gain, is narrow, a few percent of the center frequency, and decreases with increasing gain, so it is often used in fixed-frequency application. Dish antennas are capable of higher gain than the Yagi antennas and therefore can have a farther reach in space and achieve higher data rates. 2m S-band dish (Radius, 1.5 meters) antenna , LNA and cavity filters for

S-band (2200 – 2290 MHz or 2400 – 2450 MHz).It crosses the conventional boundary between the UHF and SHF bands at 2.45 GHz.

TNC and AX.25 protocol

A terminal node controller (TNC) is a radio network device used to communicate with AX.25 packet radio networks. The TNC manages data communication across the network.The TNC contains all the intelligence needed to communicate over an AX.25 network, no external computer is required. All of the network's resources can be accessed using a dumb terminal. AX.25 is often used with a TNC because it costs less. Typically, this device consists of a dedicated microprocessor, a modem, flash memory and software. The main function of the MCU is to implement the AX.25 packet protocol in the embedded source codes. Received signals are demodulated, the data unformatted, and the output sent to the terminal for display.



(Application of a TNC in communication between ground station and CubeSat)